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ORIGINAL ARTICLES.

Four "Felstone" Intrusions in Central Berwickshire.

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(PLATE XXV.)

CONSPICUOUS on Sheet 15 of the quarter-inch maps of the Geological Survey of Scotland are a group of four masses of igneous rock marked " F ". They occur in Berwickshire about three miles west of the county town of Duns, and form the eminences of the Dirrington Laws, Blacksmill Hill, and Kyleshill. These hills reach considerable heights, Dirrington Great Law being 1,309 feet high and Dirrington Little Law 1,191 feet, while Kyleshill and Blacksmill Hill are 933 feet and 905 feet respectively. They may be considered to form the southern foothills of the Lammermuir range, and overlook to the south the fertile valley known as the Merse of Berwickshire. They are bleak heather-covered slopes, where extensive sheep-grazing is carried on, and except on Kyleshill, which is sparsely wooded on its southern slopes, scarce a tree is to be seen. A large part of the lower slopes is boggy ground, and it has been necessary to construct many open drains in order that it may be fit for sheep-grazing.

Bibliography.

Little mention of these intrusions has been made in previous geological literature. In the Memoir of the Geological Survey for East Lothian (1866)[1] passing reference is made to the "felstone" of the Dirrington Laws, and it is again mentioned in the newer edition (1910).[2] In his *Ancient Volcanoes of Great Britain* Sir Archibald Geikie[3] refers to these "felstone" masses and incorporates a horizontal section drawn across the Dirrington

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[1] "The Geology of East Lothian," *Memoir Geol. Survey*, 1866, p. 26.

[2] "The Geology of East Lothian," *Memoir Geol. Survey*, 1910, p. 23.

[3] *Ancient Volcanoes of Great Britain*, vol. i, pp. 290–1.

Laws and Blacksmill Hill, showing their relations to the Palaeozoic sediments among which they occur. They are represented as isolated bosses penetrating the Silurian strata, and covered unconformably by the Upper Old Red Sandstone conglomerates. In an essay on the geology of Berwickshire, Mr. David Milne[1] refers to the Dirrington Laws as consisting of "Claystone Porphyry", while Kyleshill is a "Felspar Porphyry". No other literature on these intrusions is known to the writer, and no petrological description of these rocks has been published.

FIELD CHARACTERS.

The four intrusions are to be found mapped on the scale of one inch to the mile, partly in the north-east corner of Sheet 25, and partly in the south-east corner of Sheet 33 of the Geological Survey maps. A reproduction on a similar scale accompanies this communication.

They will be seen to occur among conglomerates and sandstones of Old Red Sandstone age. The strata are horizontal or have only a very slight dip, up to 5°, to the south, or south-east at parts. No actual contracts of the igneous rock and the sediments are visible, and it is no simple matter to decide whether the intrusions are previous to, or later than, the conglomerates. This question of the age of the masses will be discussed at a later stage.

Exposures of fresh rock are never strikingly good; most of the specimens collected came from small old quarries where the rock had been removed for the construction of walls, and scrapes on the hillsides. There is only one large quarry, on Kyleshill, near the summit, where the rock has been extensively worked for road metal, and a large face may be seen.

The field characters of the four intrusions will now be described separately, the western intrusion being taken first.

Dirrington Little Law.

The mass of igneous rock which forms this hill lies just to the north of the Duns–Westruther road, and has a surface extent of about one square mile. It is exposed in several old quarries on the southern slopes of the hill, where it has been worked to provide material for walls, etc., and in some scrapes on the sides of the hill.

The rock is in a fairly fresh state, is very fine grained, and splintery. It is light reddish-brown in colour where fresh, but lighter and pinkish where it has been exposed to the weather. The rock from the quarries to the south has a flinty appearance, and sometimes a fluxion cleavage is developed.

It is felsitic and none of the constituent minerals are obvious in the hand specimen except occasional phenocrysts of felspar and quartz, and little dark specks of a ferromagnesian mineral. These latter appear to be more numerous or at least are more noticeable in the lighter coloured rock. Nearer the summit of the hill the reddish colour alters to lilac and purple shades, but the rock has lost its splintery character. Where the rock is badly decomposed it becomes dark red in colour and rather resembles a red sandstone.

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[1] "A Geological Survey of Berwickshire," *Trans. of the Highland and Agricultural Soc. of Scotland*, 1837, vol. xi, pp. 171–253.

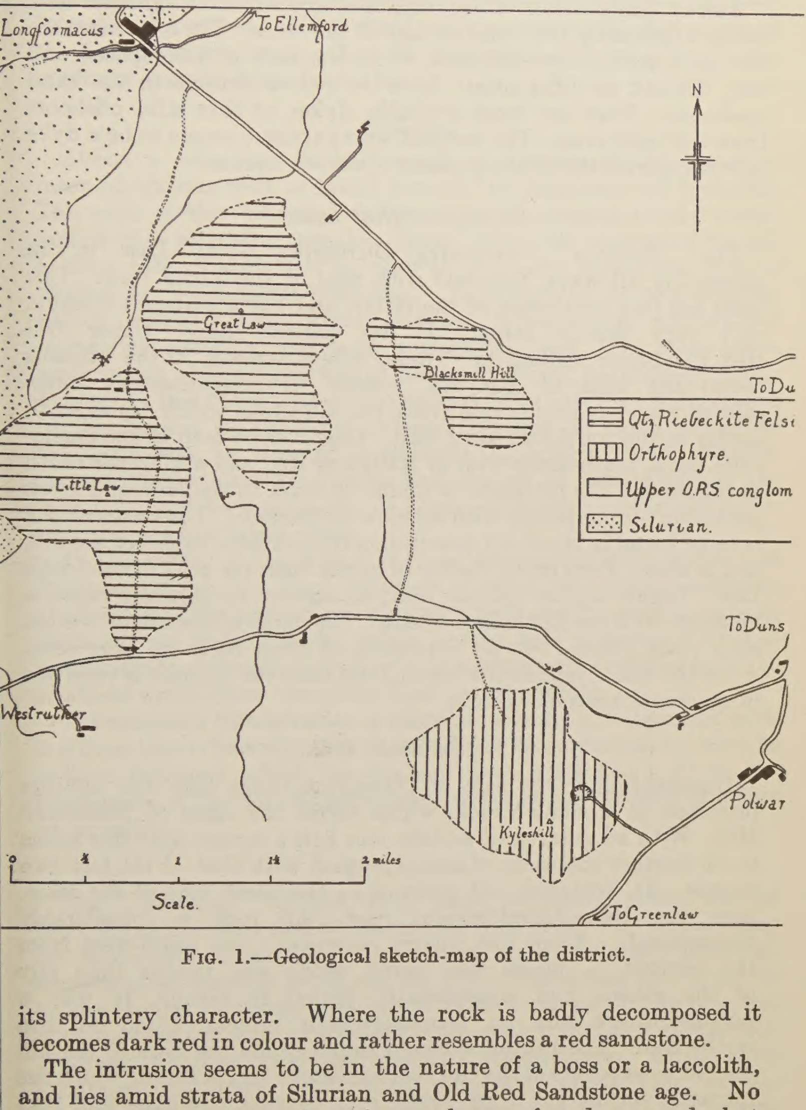

FIG. 1.—Geological sketch-map of the district.

The intrusion seems to be in the nature of a boss or a laccolith, and lies amid strata of Silurian and Old Red Sandstone age. No contacts of igneous and native rock are found exposed, but on the north-west side the Silurian greywackés can be seen dipping north-north-west at angles of 40 to 60 degrees. In the stream north of Kippetlaw the Upper Old Red Sandstone can be seen dipping at small angles to the east. These strata are conglomerates with a few intercalated bands of course red sandstone.

Among these strata three separate exposures of igneous rock occur, apparently the same as that of the mass. The exposures are not good, no contacts are seen, while the rock is decomposed and very difficult to differentiate from the red sandstones in the hand specimen. They are most probably dykes or thin sills, offshoots from the main mass. The farthest west exposure seems to be a dyke as it cuts across the bedding planes of the sandstones.

Dirrington Great Law.

The "felstone" composing Dirrington Great Law is, in practically all ways, identical with that of the Little Law. This mass lies just north-east of the latter, and has a surface extension only very slightly larger. It lies entirely amid Upper Old Red Sandstone sediments. These, where exposed in the streams round the base of the hill, consist of conglomerates intercalated with bands of coarse gritty red sandstone which dip at small angles to the south and south-east. They can be seen in the Cattleshiel Burn, south-south-west of Hallywell Rig, and also to the north of the mass. The intrusion is similar in form to the last, and in all probability is connected with it below the surface. The freshest rock is to be found in small old quarries on the southern slopes of the hill, and is there, if anything, darker in colour than the rock of the Little Law. Higher up the hill, the rock, as exposed in various scrapes, is identical with the Little Law felsite. The north of the hill is covered with platy screes, but no exposures of fresh rock are here seen. As in the last intrusion the felsite from near the summit is very fine in grain and has a lilac colour.

Blacksmill Hill.

Immediately to the east of Dirrington Great Law lies another intrusion of a similar rock, which forms the mass of Blacksmill Hill. With an outcrop of a little over half a square mile this seems to be another intrusion of rock identical with that of the last two masses. In numerous old quarries on the north side of the mass, near the Duns–Longformacus road, this rock is considerably decomposed. From one quarry, however, just south-west from the summit, a felsite was found which was fresher than any of the others, and consequently darker in colour. It was a purplish-brown and no ferromagnesian mineral could be seen in the field. The heather-covered slopes round the base of the hill offered no exposure of the Old Red Sandstone strata among which the intrusion occurs, but to the south-west, between this mass and that of the Great Law, the sandstones may be seen on what is known as Inch Moor, and they are again dipping to the south at an angle of about 5°.

It seems probable that the three intrusions already mentioned form separate outcrops of one large mass of felsite, in the nature of a laccolith. The answer to the question of whether this mass has been intruded through the O.R.S. strata or previous to the deposition of the latter, which would then lie unconformably upon it, is not apparent and will be discussed later.

Kyleshill.

About a mile and a half south of Blacksmill Hill another mass of igneous rock is found forming the eminence of Kyleshill. The rock of this intrusion differs from the masses to the north, and is of a somewhat peculiar type. Near the summit of the hill a large face of rock can be seen in a quarry where the rock is worked for road metal chippings. It is seen to be of a reddish-brown colour with white patches representing decomposed felspar phenocrysts, and is of a trachytic type. The mass has a surface area of three-quarters of a square mile and lies entirely among Upper Old Red Sandstone conglomerates. The latter are well exposed in the stream to the north where they dip at small angles to the south-east, i.e. dipping in towards the igneous mass. No contacts with the mass are visible, and though at some localities the margin cannot be far distant, no apparent disturbance or alteration of the strata has taken place.

In the centre of the Kyleshill mass, about 250 yards north-west from the quarry, is a single exposure of a dark blue rock of andesitic appearance. The normal red trachytic rock can be seen at varying distances to within thirty yards around this exposure, but it is impossible to gather from such a poor exposure any evidence as to the relations which these two rocks bear to one another.

The nature of this intrusion is therefore obscure ; if the main mass is a boss, how is this exposure of andesite to be explained, unless it be a later intrusion which has pierced the earlier one ? From the appearance of the hill the main mass certainly has the look of a boss or laccolith.

PETROLOGY.

The "felstones" of the three more northerly areas, i.e. of the Dirrington Laws and of Blacksmill Hill, being very similar, may be described collectively. Specimens were collected from all exposures at varying levels on the hills. There was not found to be any regular variation from top to bottom except for the presence of phenocrysts of soda plagioclase in the rock from the higher levels. The rock is perhaps best described as a quartz-felsite. In the hand specimen the only constituent minerals which can usually be discriminated are the small phenocrysts of felspar and quartz to be seen in the freshest specimens, very small black spots of a ferromagnesian mineral, and a few sporadic biotite flakes. As mentioned before, the rock from the lower exposures is harder, flinty, and splintery; from the higher levels it is softer and lighter in colour. This, however, is probably due to the lower exposures, where the rock has been quarried, giving fresher specimens. In an old quarry to the south of Blacksmill Hill, a hard fresh example of the rock was a dark brown colour and very flinty in appearance, whereas the old quarries on the north side yielded a crumbly decomposed rock, which resembled a sandstone. From the top of the Dirrington Laws the rock was pink or lilac in colour, but was not so fresh as at lower levels.

Under the microscope this felsite consists of microphenocrysts of quartz, and orthoclase felspar of the sanidine type, embedded in a felsitic base of orthoclase and quartz, with some little ferromagnesians and iron ore.

The quartz phenocrysts are clear hexagonal idiomorphic crystals, but in some cases they are rounded and embayed, due to their resorption by the residual liquid before the rock finally consolidated. The felspar phenocrysts are often fresh and of the clear, glassy sanidine variety, but sometimes they have been altered or partially resorbed. In the very freshest of the rock slices some of the orthoclase crystals are seen to have as a core, a polysynthetic twinned plagioclase crystal. This plagioclase has a slightly higher refractive index than the surrounding orthoclase, but owing to the smallness of the crystals the extinction was difficult to ascertain. It seemed to extinguish at small angles up to 10°, indicating an oligoclase-albite. Seemingly the orthoclase phenocrysts have grown round a nucleus of acid plagioclase. It is noticeable that, when decomposition sets in, it is this core of plagioclase which is first to be altered. The felspars are at some localities replaced by a secondary, infiltrated mineral, which is fibrous and practically colourless. This mineral, under cross nicols, shows a spherulitic structure, and has low interference colours. It was at first taken for cryptocrystalline silica, but it was found to have a refractive index distinctly higher than Canada balsam, so a micro-chemical test was made. After treating an uncovered slice for five minites with hydrochloric acid and staining with methylene blue, this mineral readily took up the stain. It is therefore probably a colourless variety of chlorite. It is noticeable that round decomposed felspars there is a concentration of iron ore.

In slices of the rock from near the summit of Blacksmill Hill, in which the felspars are very fresh, a very occasional plagioclase is seen among the phenocrysts. It is of albite and this seems to point to an increase in the soda content.

The ground-mass of these rocks consist of a few biotite flakes, some irregular aggregates of a strongly pleochroic ferromagnesian which have often been altered to iron ore, in a microfelsitic base of quartz and orthoclase. Iddings has applied the term " microfelsitic " to a base in which no definite differentiation between the orthoclase and quartz can be made, and it is in this sense that it is used here. Some clear patches of quartz occur, a few laths of felspar have crystallized, but most of the base is indeterminate. Occasionally stellate groups of small felspar crystals are seen, a few spherulitic growths of quartz and felspar occur, and small areas of micropegmatite can sometimes be made out. In order to give some indication as to the composition of the base a staining test was made. It was found that after treating a slice for one hour with hydrochloric acid, carefully washing and staining, all the indeterminate matter of the base had absorbed the stain, but the clear grains and areas of quartz remained colourless. This seems to show that the base has not been silicified as has been the case with the Old Red Sandstone trachytes and rhyolites of the Pentland Hills.[1]

In the more decomposed examples a certain amount of infiltrated chloritic matter occurs. The iron ore is mostly haematite although some magnetite is also present. The haematite is spongy and seems to have been derived by decomposition of the ferromagnesian.

The identification of this ferromagnesian mineral presented some difficulty. It occurs in small broken flakes and irregular aggregates in the freshest slices of the rock. In the more decomposed examples these aggregates have been entirely altered to spongy haematite and there are only a few broken scraps of the mineral to be seen in a half decomposed state.

It is highly pleochroic from a light yellow, through a green to a dark green or opaque. In some cases the dark green has a blueish tinge. It has a high refractive index, low polarisation colours, and practically straight extinction. It seems to be distinct from the biotite in the rock as it does not show the perfect basal cleavage of the latter, and has a characteristic habit. Biotite is seen in these rocks, not in great amount, but almost all slices show a few flakes. This other mineral, however, shows the development of a prismatic cleavage in some cases, which gives flakes having transverse absorption, i.e. maximum absorption takes place when the long axis of the flake is transverse to the vibration direction of the polariser, the opposite from biotite. Many of the flakes seem to have parallel absorption. The pleochroism is more intense than that of the normal biotite. In some cases the flakes seemed to have crystal terminations, at least they do not always have the irregular endings common to biotite flakes. It was compared with the riebeckite of the quartz-riebeckite-felsite from the West Eildon Hill described by Lady McRobert,[2] and was found to be practically identical in habit and optical properties ; indeed the rocks themselves are very similar (Plate XXV, Fig. 1). The fact that our mineral does not show the deep blue colour of some riebeckite may be explainable by its partial alteration to haematite. Where it has decomposed to haematite the latter has exactly the same spongy habit as the iron ore in the West Eildon rock. It was therefore concluded that this ferromagnesian was most probably riebeckite, and in such a case the rock would become a quartz-riebeckite-felsite. As an attempt to verify this conclusion, a magnetic separation was taken from a powdered specimen of the rock. Under the microscope this separation was seen to contain this ferromagnesian along with grains of iron ore. Some of the latter showed a greenish tinge round their margins, where they were not quite opaque. Some of this separation was treated for a short time with dilute hydrochloric acid and again examined. Part of the opaque grains had been dissolved away and were seen to consist of the ferromagnesian along with iron ore. This points to the fact that the ferromagnesian has decomposed to iron ore directly, which might happen in the case of riebeckite. Riebeckite would again be more easily obtained in a magnetic separation than biotite. The results of an analysis of the rock will be shown to prove that riebeckite is more likely than biotite (see p. 540).

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[1] " The Geology of Edinburgh Dist.," *Mem. Geol. Survey*, pp. 37–41.

[2] Rachael Workman McRobert, " Acid and Intermediate Intrusions and Associated Ash Necks in the Neighbourhood of Melrose," *Quart. Journal Geol. Soc.*, vol. lxx, 1914, pp. 303–14, esp. p. 308.

Kyleshill.

The rock forming the main mass of Kyleshill is an orthophyre. In the hand specimen it is a reddish-brown conspicuously porphyritic rock. The phenocrysts are of felspar set in an orthophyric or trachytic base, and on a weathered surface these are white in colour, giving the rock a spotted appearance.

Under the microscope the rock consists of phenocrysts set in a base of stumpy laths of orthoclase, quartz, and haematite. The felspars are all either untwinned or simply twinned, and have a lower refractive index than balsam. The phenocrysts are usually made up of an aggregate of untwinned crystals, giving glomeroporphyritic structure. They show extinction angles up to 12°, and are probably a soda orthoclase. Round them the felspars show marked fluidal arrangement. The rock is none too fresh and the felspars have haematite developed along their numerous cracks. The interstitial quartz stands out in relief as it is of higher refractive index than the felspar laths. Haematite is abundant, and it is this mineral which gives the rock its red colour. It is scattered throughout the rock, in some places filling in the spaces between the orthoclase laths, in others forming pseudomorphs after some ferromagnesian mineral. These latter are sporadic and indefinite in shape, and there is no fresh ferromagnesian found. Very occasionally the iron ore occurs along with a secondary epidote in forms which suggest augite.

There is a noticeable concentration of haematite round the phenocrysts. A little secondary chlorite is seen in irregular patches in some slices; this is sometimes stained red by the iron oxide. Some of the felspar phenocrysts have begun to be replaced by carbonates in the centres of the crystals.

Apatite is an abundant accessory in small needles of high refractive index (Plate XXV, Fig. 3).

The dark blue rock from the single exposure in the centre of the Kyleshill mass appears to be of the nature of an andesite. On the weathered surface this rock is red and porphyritic, and closely resembles the orthophyre in the hand specimen, but this red colour only persists to a depth of a few inches. It then becomes gradually darker, passing through a stage where it is purple with red areas in the neighbourhood of any cracks which occur, to a rock of a dark blue shade in which phenocrysts of felspar and augite can be seen in the field.

Under the microscope this rock is resolved into felspar phenocrysts and some augites set in a ground mass of felspar, granular augite, and abundant small grains of magnetite (Plate XXV, Fig. 4).

There are clearly two generations of felspar and augite. The phenocrysts are idiomorphic crystals of dull yellowish-brown augite which are altered in parts to carbonates, and may show zoning; and large plagioclase felspars showing twinning on both albite and pericline laws. The twin lamellae are in some cases very fine, but the composition judged from optical properties approximates to andesine. It exhibits extinction angles up to 17°, and has a refractive index above that of Canada balsam.

The ground mass consists of felspar laths of a second generation, numerous granules of light brown to colourless augite, and abundant magnetite grains with interstitial quartz and felspar. The felspar laths are an oligoclase-andesine, but the interstitial felspar seems to be of a slightly more acid type.

Where the rock is red in colour the iron ore is seen to be mostly altered to haematite or limonite. This alteration is clearly the effect of weathering, as it is only to a depth of a few inches from the surface and along cracks in the rock that the haematite is seen. The felspar phenocrysts have numerous inclusions and are often embayed by the ground mass, and much resorbed, giving curious shapes. The augite crystals also contain inclusions mostly of magnetite.

AGE AND AFFINITIES.

There are several types of rocks from the Midland Valley of Scotland with which these rocks are comparable.

They may first be compared with the other "felstones" of Berwickshire which are found in the eastern part of the county. They are, however, distinct from that type. These "felstones", which are found intruded through the Silurian tract adjacent to the coast, and the lower Old Red Sandstone in the neighbourhood of Eyemouth, are mostly in the former case porphyrites, and in the latter case decomposed andesites. They have nothing in common with the felsites under consideration. A greater similarity is shown to the trachytes, rhyolites, and microgranites of the Pentland Hills.[1] These are of an Old Red age, but are mostly silicified and contain no ferromagnesian except a few biotite flakes. They have also a lower soda percentage.

The rocks from the Dirrington Laws have a greater resemblance to the felsites described by Lady McRobert [2] from the Eildon Hills and neighbouring acid intrusions. They bear a great similarity to the latter, both in occurrence and in petrological description. The "platy screes", "fluxion cleavage", "lower layers pink, upper layers purplish" are descriptions which might equally apply to our intrusions. They both contain riebeckite, or pseudomorphs of iron ore after such a mineral. The quartz riebeckite felsite of the West Eildon Hill is indeed almost identical with our rocks (cf. Plate XXV, Fig. 1, with fig. 2 of plate accompanying Lady McRobert's paper).

In this paper the Eildon Hill rocks are assigned to a Carboniferous age, so we must examine the evidence as to the age of the intrusions to the east. Sir A. Geikie [3] assigned them to the Old Red Sandstone period of activity on the grounds that the Upper Old Red Sandstone conglomerates contained numerous pebbles of the "felstone". These conglomerates were carefully investigated and pebble analyses made at various points close to, and at a distance from the intrusions. As will be seen from the analyses quoted below there does not appear to be any regular increase in the percentage of felstone pebbles as we approach the igneous masses. These "felstone" pebbles were found to be largely of the nature of porphyrites, and in general much more closely resembled the rocks of the intrusions in the Silurian tract than those of our masses. A number of the pebbles which in the hand specimen were most like our rocks were sliced, but they all differed considerably from the latter. Some were definitely porphyrites, some decomposed andesites full of haematite, others which had a more felsitic structure contained much secondary quartz, but in no case showed any signs of having contained any ferromagnesian such as occurs in the rocks under consideration. It seems that these pebbles have been derived from the igneous intrusions in the Silurian and from the Old Red lavas and intrusives. It is possible, therefore, that our intrusions are later than the Upper Old Red Sandstone and intruded through it. Against this view, we see no signs of alteration in the conglomerates or sandstone even where the latter are exposed at what cannot be a great distance from the margin of the intrusion. At some such spots, e.g. north of the Great Law, they are seen to dip slightly in towards the mass. This does not agree with the theory that they were unconformable on the igneous rocks. The igneous rocks which are found north of Kippetlaw amid the

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[1] "The Geol. of Edinburgh and District," *Memoir Geol. Survey of Scotland*, 1910, pp. 37–41.

[2] Op. cit., 308–9.

[3] Op. cit., p. 291.

Upper Old Red strata appear to be intruded thereinto and are the only positive evidence afforded.

The orthophyre of Kyleshill has no very close similarity to any of the rocks described from the Eildon complex, although it might easily be classed along with the porphyritic sanidine-trachyte of the North Eildon Hill.[1] It does not, however, as in the latter case, bear quartz phenocrysts. The andesite does not belong to a type characteristic of the Carboniferous activity; it is more like a product of the Old Red igneous action, but the conglomerates round the Kyleshill mass showed no pebbles of such a rock. It is therefore assumed that the masses to the north are probably of a Carboniferous age, and belong to the same period of action as the closely related rocks of the Eildon Hills, Black Hill, and Bemerside, while the Kyleshill rock may or may not be of the same date.

The following were the results of the analyses of the conglomerates:—

	1	2	3	4	5
"Felstones" (mostly porphyrites [60%] and ashy brecciated felsites like those of the coast district. None resembling the orthophyre or the andesite)	50	58	14	40	18
Quartzites and quartz pebbles . .	42	26	14	4	4
Sandstones	6	6	20	24	12
Silurian greywackes . . .	2	10	52	32	66

1. From stream north of Kyleshill, near margin of the orthophyre, but 1½ miles from the felsite. Dipping south-east *c.* 10°.

2. From stream north of Kyleshill, ½ mile from the latter and 1 mile from the felsite, nearer to the Silurian hills. Dipping south-south-east at small angles.

3. South-south-west from Hallywell Rig, 250 yards from the felsite, nearer to the Silurian. Dipping south-east 5°.

4. North of Great Law, north-west from Dronshiel farm, ¾ mile from the felsite, and farther from the Silurian. Dipping south-east at small angles.

5. Hardens Hills, about 3 miles from the felsite, and near to the Silurian uplands.

From the above analyses the only regular variation seems to be that of the Silurian pebbles, which bear a direct relationship to the distance from the Silurian tract. The "felstone" content seems to vary irregularly and to bear no real relation to the proximity of the masses treated in this paper. This is taken as evidence of the later age of these masses.

An analysis of the freshest of the felsite, made by Dr. Jacob of Zürich, is quoted below along with those of an Old Red rhyolite,[2] a riebeckite-granophyre from Shetland,[1] and a riebeckite bearing orthophyre from Ailsa Craig.[2] It is unfortunate that no analysis of the Eildon Hill rock is available.

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[1] Op. cit., pp. 307–8.

[2] *Mem. Geol. Survey Edinburgh District*, 1910, p. 39.

The felsite will be seen to be an alkaline rock with a fairly high soda percentage and deficiency in alumina, and from the norm it appears that the presence of a soda bearing amphibole such as riebeckite is a strong possibility.

The absence of magnesia shows that the main ferromagnesian cannot be a mica.

The analysis agrees very closely with that of the riebeckite from Shetland. The norms of these two rocks give misleading impressions. Although the Berwickshire rock shows a higher soda percentage, it shows a smaller amount of ferromagnesian, which in the norm is calculated as acmite. This is due to the fact that this rock has also a higher alumina content, and a larger proportion of the soda is therefore calculated as albite. It may be, however, since our riebeckite does not show exactly the pleochroism of normal riebeckite, that it is an aluminous variety. In such a case some of the alumina, which in the norm was calculated in the albite, would be contained in the riebeckite, and the soda and silica combined with this amount in the normative albite, would be free to give a larger proportion of riebeckite and free quartz respectively. The riebeckite might also contain traces of the lime and manganese oxide shown in the analysis and would therefore be of a composition intermediate between riebeckite and arfvedsonite.

ANALYSES.

	A.	B.	C.	D.
SiO_2	74·75	74·79	71·56	72·78
TiO_2	·08	·36	·28	·19
ZrO_2	·00	·00	·00	·03
Al_2O_3	12·59	10·93	14·02	12·86
Fe_2O_3	1·47	2·26	1·26	3·14
FeO	·53	1·64	1·46	·26
MnO	·01	·00	·00	·09
MgO	·00	·04	·21	·83
CaO	·37	·53	·42	·92
BaO	·00	·00	·00	·05
Na_2O	4·68	4·25	6·46	2·31
K_2O	4·95	4·79	3·97	4·14
$H_2O +$	·46	·19	·43	1·89
$H_2O -$	·11	·27	·08	1·05
P_2O_5	·03	·00	tr.	·14
CO_2	·00	·00	—	—
S	—	—	—	tr.
Cl	—	—	—	tr.
	100·03	100·05	100·15	100·68

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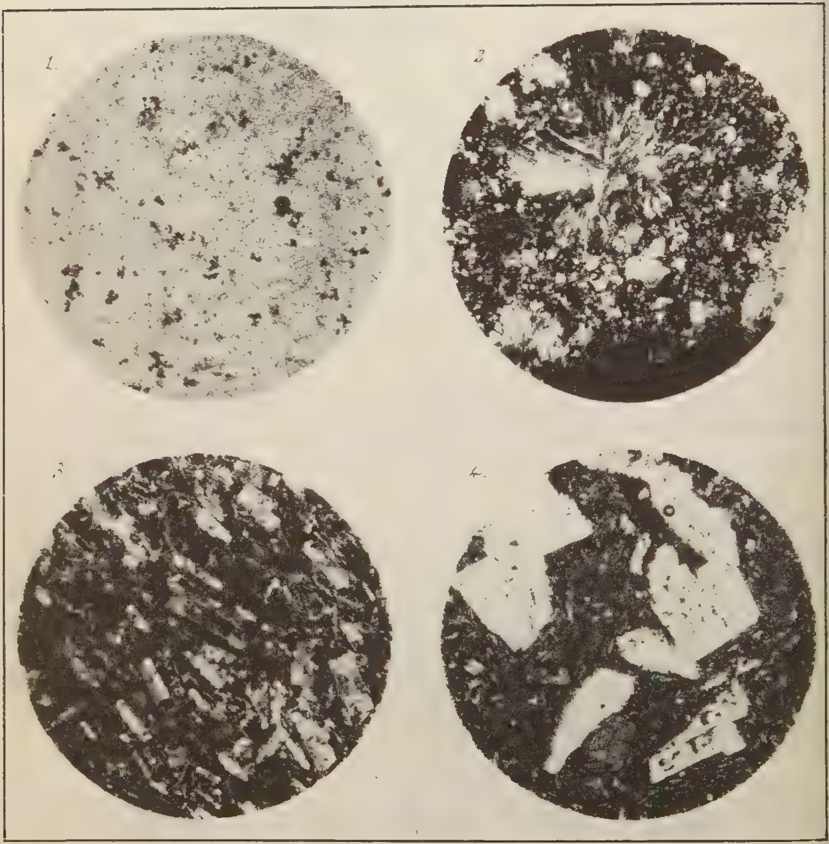
[1] F. Coles Phillips, GEOL. MAG., Vol. LXIII, 1926, p. 75.

[2] (Described) J. J. Teall, *Mineralogical Magazine*, vol. ix, pp. 219–22.



THE "FELSTONES" OF CENTRAL BERWICKSHIRE.

NORMS.

	A.	B.
Quartz . .	29·26	31·74
Orthoclase .	29·25	28·36
Albite . .	36·95	29·34
Acmite . .	2·32	5·54
Diopside . .	—	3·38
Magnetite . .	·97	·46
Ilmenite . .	·22	·61
Apatite . .	·07	—
Water, etc. .	·57	·46
	99·61	99·89

A.—Quartz-riebeckite-felsite, Dirrington Little Law, south side. Analyst, Dr. J. Jacob.

B.—Riebeckite-granophyre, Grut Wells, Ronas, Shetland, quoted from F. Coles Phillips, GEOLOGICAL MAGAZINE, Vol. LXIII, 1926, p. 75.

C.—Riebeckite-microgranite, Ailsa Craig. Analyst, Raoult. Quoted from A. Lacroix, Paris, *Comptes Rendus*, Tome 177, 1923, pp. 437–8.

D.—Rhyolite, Woodhouselee, Pentland Hills. Analyst, Dr. Pollard, quoted from *Geol. Survey Memoir Edinburgh District*, 1910, p. 39.

SUMMARY.

The three masses of Dirrington Great Law, Dirrington Little Law, and Blacksmill Hill consist of riebeckite felsite, closely allied to the rock of the neighbouring Eildon Hills and most probably contemporaneous with it, i.e. they are of a Carboniferous age. They may represent the denuded remains of a laccolith which has been intruded into upper Old Red Sandstone conglomerates. The fourth mass forming Kyleshill is an orthophyre, with which is associated an andesite. The relations of these two rocks are obscure, and they may, or may not be, of the same age as the other three masses.

ACKNOWLEDGEMENTS.

The author wishes to express his indebtedness to the Carnegie Trust for the Universities of Scotland, for financial assistance which enabled him to carry out the research; to Mr. Harker, Sedgwick Museum, Cambridge, and to Dr. Walker, of St. Andrew's University, for their valuable advice.

EXPLANATION OF PLATE XXV.

FIG.

1.—Quartz-riebeckite-felsite, Dirrington Little Law, south side, showing dark aggregates of pleochroic riebeckite in a microfelsitic base of quartz and orthoclase. Ordinary light, × 30 diameters.

2.—Quartz-riebeckite-felsite, Dirrington Great Law, showing spherulitic area of micropegmatite. Crossed Nicols × 120 diams.

3.—Orthophyre, Kyleshill quarry, showing orthoclase laths with fluidal structure. Crossed Nicols, × 30 diams.

4.—Andesite, Kyleshill north-north-west, showing resorbed andesine phenocrysts and one augite, in a base of felspar and small granular augites with abundant magnetite. Ordinary light, × 30 diams.

The Gneiss of Inishtrahull, County Donegal.

By William J. McCallien, D.Sc., Lecturer in Geology in the University of Glasgow.

(PLATE XXVI.)

I. Introduction.

THE previous literature on the pre-Cambrian rocks of Ireland is considerable in amount. The views of the early workers are briefly referred to in the *Handbook of the Geology of Ireland*, by G. A. Cole and T. Hallissy, published in 1924. This work doubtless expresses the opinion of Irish geologists of the present day.

At the British Association meeting in 1881 Hull gave six localities in western and north-western Ireland in which he believed there existed rocks similar in age to Murchison's Fundamental Gneiss of Sutherlandshire and Ross-shire (also in *Trans. Roy. Soc. Dublin*, vol. i, part xviii, 1882). At the same meeting Kinahan objected strongly to the views of Hull (also in Geol. Mag., 1881). Later Callaway (*Q.J.G.S.*, 1885) considered the Donegal granite to be intrusive. A similar view had been put forward many years previously by Sir R. Griffith and Professor Haughton. In the memoir on the Geology of north-west and central Donegal, Hull abandoned his former view regarding the Archaean age of the Donegal granite, but in the Prefatory Note to the same memoir Sir A. Geikie still believed in the Archaean age of the gneisses of western Mayo and southern Galway, and stated that he had satisfied himself that a core of Archaean gneiss rises from under the schists in County Tyrone.

In the *Handbook* it is stated that in Ireland there is no certain exposure of a rock-floor of a fundamental and " primitive " character. " Ancient gneisses occur, but they seem to have resulted in all cases from the invasion of sedimentary rocks by granite " (p. 6).

The sediments older than the Arenig in Ireland are seen in many parts of Mayo, Galway, and Donegal in the Irish Free State as well as in Londonderry, Tyrone, and Antrim in Northern Ireland. They are thought to be the equivalent of the Dalradian of Scotland. It cannot be said at present whether the whole of the rocks of the mainland belong to the Dalradian or not.

According to Cole and Hallissy the oldest rocks in Ireland are the biotite-gneisses and schists of eastern Tyrone. The writer has not examined these rocks in the field, but he thinks they are the continuation of the biotite-schists and gneisses described by him in north-eastern Antrim. These he has assigned to the Loch Lomond sequence of Scotland, and he thinks that we are not yet in a position to say that rocks older than these in the Dalradian sequence itself will not be found in Ireland.

By the intrusion of granitic material into the Dalradian schists of Tyrone and Londonderry at Fir Mountain there has resulted a composite rock similar to the gneiss of the south-western part of the pre-Cambrian of Ireland. According to Cole (*Q.J.G.S.*, lv, 1899) this granite is of pre-Old Red Sandstone and probably pre-Cambrian age. The gneisses of the Ox Mountains (Sligo and Mayo), originally considered fundamental gneiss, are composite gneisses resulting from the invasion of sediments by granitic material.

Gneisses of intrusive or composite origin are believed by the Geological Survey of Ireland to occur at Torr Head on the north-eastern coast of Antrim. These rocks are normal Dalradian sediments and epidiorites. The latter have their greatest development on Torr Head, where they are associated with crystalline limestone, probably the Loch Tay Limestone of Scotland.

In the description [1] of the specimens dredged from the Atlantic to the west of the pre-Cambrian area of Ireland a great many of the rocks are described as gneisses, but in many cases normal Dalradian sediments and normal granites seem to be grouped with them. The writer has seen gneisses brought by trawlers from the Porcupine Bank, and they resembled those of Inishtrahull.

From the above remarks the writer thinks it safe to assume that at the present day the Lewisoid gneisses, associated for the most part with the Dalradian rocks of Ireland, are believed to be due entirely to the injection of the sediments by a granitic magma. According to the *Handbook of the Geology of Ireland* (p. 49) " the geological history of Ireland begins in Algonkian times with the laying down of the Dalradian sediments in a sea where muds alternated with sandbanks, and where limestones and dolomites were occasionally formed ".

II. Northern Donegal.

During a study of the Dalradian rocks of Donegal the writer had an opportunity of visiting the little island of Inishtrahull off the most northerly point in Ireland, and if passible was struck, as he thinks most Scottish geologists would likewise be, by the striking similarity between the rocks of the island and the Lewisian Gneiss of Scotland. Since then, after a study of the material collected, he is convinced that Inishtrahull Island is composed of Lewisian Gneiss. The island is indicated on the one-inch map [2] of the Geological Survey of Ireland as gneiss, and it is recognized that it bears a close resemblance to the Archaean rocks of Sutherlandshire, and is quite dissimilar in character to any other rock of the district of Inishowen described in the same memoir.[3]

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[1] *On Rock Specimens Dredged from the Floor of the Atlantic, and their bearing on submarine geology.* By G. A. J. Cole and T. Crook, 1910. *Mem. Geol. Surv. Ireland.*

[2] Sheet 1 of the Geol. Surv. Ireland.

[3] " The Geology of Inishowen " : *Mem. Geol. Surv. Ireland.* By E. Hull, J. Nolan, R. J. Cruise, A. McHenry, and J. S. Hyland, 1890.

III. INISHTRAHULL.

This little island (Fig. 1), about one mile long from east to west, a little less than half a mile from north to south, and about 140 feet high, lies in Lat. 55° 26′ N. and Long. 7° 14′ W., 5 miles from the northern coast of Donegal. Inishtrahull is 3 miles north-east of the most northerly occurrence of Dalradian rocks in the Garvan group of islands off Malin Head village. The Garvans are composed of quartzite dipping south-eastward and similar to that on the neighbouring parts of Inishowen. Half a mile north of Inishtrahull are smaller islands—the Tor Rocks, including Torbeg and Tormore—which have not been examined by the writer, but which appear to be of the same material as Inishtrahull.

In the memoir on the Geology on Inishowen (p. 21) the rocks of the Malin Head peninsula and those of the islands off Malin Head village are considered to be the oldest rocks of the Dalradian sequence. Further the rocks with which we are now dealing are supposed to be older than the quartzites and associated rocks of the mainland.

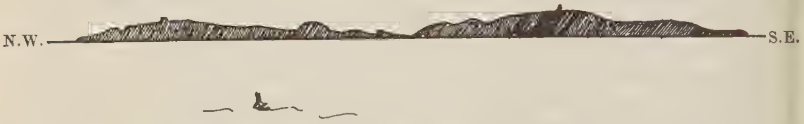

FIG. 1.—Inishtrahull from Dunmore Head, Culdaff, 10 miles distant.

In hand specimens the Inishtrahull rocks vary from massive flesh-coloured granitic rocks to typical pinkish and greenish Lewisoid gneisses with basic types represented by dense hornblende-schists. Light-coloured acid veins are common.

The slices of the Inishtrahull gneiss which have been examined microscopically are easily divided into three groups; those with distinct foliation, those with distinct granulitization but little secondary foliation, and one slide of a dark greenish basic rock practically devoid of quartz.

Those rocks with distinct foliation are the extremely crushed members of the suite. The foliation is defined by biotite, muscovite, and dark iron ores. The felspar is chiefly albite and microcline, and large fragments of microcline are traversed with cracks filled with biotite and granulitic material. In one there is a little brown hornblende.

The other rocks, though not markedly foliated, are closely associated with the above and give more indication as to the history of the rock subsequent to consolidation. They are now almost in the form of microscopic grits, and they show good examples of all stages of granulitization. In some the material of the rock is completely broken down, in others there is marginal granulitization of the larger felspar fragments. A remarkable feature of the rocks is the almost complete saussuritization of the plagioclase felspar, which has been replaced by alkali-felspar crowded with evenly distributed minute prisms of epidote. Two of the slides are exceptionally rich in apatite, which is associated with concentrations of hornblende and biotite.

Some of the slices of the Inishtrahull rocks represent original hornblende-biotite-gneisses, and in one there is a dark clot of early crystalline minerals, hornblende, and biotite. The felspars in many examples of the gneiss are cracked, and the cracks are filled with secondary greenish-brown biotite. Chlorite is abundantly developed in most slides, and the new biotite is associated with it. Many of the cracks in the felspars are filled with secondary quartz.

There is only one slide of a quartz-free basic igneous rock in the collection. It consists of a pale greenish amphibole, brown hornblende, biotite, saussuritized felspar, and quantities of apatite. As in the other rocks, the biotite is developed along cracks in the felspar. Many pieces of the pale amphibole are fringed with secondary biotite. This slide compares very closely with several slides of the Islay Lewisian in the collection of the Geological Survey of Scotland.

The history of the rocks of the island told by all the slices is practically the same. The rocks show signs of remarkable crushing, which in some cases has broken up the minerals into an aggregate of small angular fragments and in others has caused marginal granulitization of the larger felspars and complete granulitization of the other minerals. It was probably as a result of the earth movements that caused the crushing that the calcic felspars were converted into saussuritic aggregates, and that the pseudomorphs and remnants were cracked and filled with minute particles of powdered materials. It is the writer's opinion that at a later stage the rocks of the island suffered baking with a widespread development of the hornfels-biotite. The result of the subsequent baking is probably responsible for the resistance which the Lewisian Gneiss of this little island has offered to the waves of the Atlantic.

IV. COMPARISON WITH OTHER AREAS OF LEWISIAN GNEISS.

A little over 30 miles distant in a north-easterly direction from Inishtrahull is the Lewisian outcrop of the Rhinns of Islay. In the memoir on the geology of Islay the following description of the rocks recalls so clearly the fragmental rocks of Inishtrahull as to merit quotation (J. J. H. Teall, p. 15):—

"The most striking petrographical feature of the specimens from various parts of the area which have been examined under the microscope is the evidence which they afford of changes due to pressure-fluxion. Relics of original constituents lie in a matrix of secondary granulitic or mylonitic material, mainly composed of quartz and felspar, but containing also minute scales of biotite and chlorite, films of sericite, and grains of epidote. The more basic as well as the more acid members of the series show, as a rule, the same evidence of profound modification by this dynamic action, the general result of which has been to crush the original constituents and thus to produce microscopic breccias, not holocrystalline schists."

The writer has had an opportunity of examining the slices of the Islay gneisses in the collection of the Geological Survey of Scotland. The resemblance between them and the Inishtrahull slices is so very striking that little doubt is left in one's mind that the rocks which they represent are of the same age. In the previous literature there is no suggestion of the Islay rocks having been contact-altered, but the same types of biotite are found as in the Inishtrahull gneisses, and in both cases the biotites occur within the felspars with the same mode of occurrence. In many examples the biotite occurs within unbroken felspars. In the Lewisian gneisses of Islay the basic felspar is represented by saussuritic aggregates like those in the Inishtrahull rocks.

The writer has also examined some of Professor Jehu's slides of the Iona gneisses, in the study of which Professor Jehu acknowledges assistance received from Dr. Campbell. The Iona gneisses are stated (Jehu, *Trans. Roy. Soc. Edin.*, liii, part 1, No. 8) to show undoubted modification by the neighbouring Ross of Mull granite. The history of the orthogneisses of Iona as described by Professor Jehu, and later confirmed by the Geological Survey, is as follows: after the formation of the rocks subsequent cataclastic effects produced shearing to a pronounced degree, most of the minerals being more or less fractured; and secondly, hornfelsing of the orthogneisses by the Ross of Mull granite. "The sections reveal the abundant production of new biotite, usually brown or greenish-brown, pseudomorphic after hornblende or in aggregates of flakes oriented in every direction; or, again, it may occur merely along the cracks and cleavages of the hornblende. The biotite is not confined to the original ferromagnesian minerals. It is found in small flakelets, usually associated with quartz, filling the cracks across the felspars, apatites, and iron ores as well, the biotite-quartz aggregates replacing completely or partially the chlorite and epidote, which infill similar cracks in the gneissic rocks outside the zone of hornfelsing."

The Iona gneisses are not quite in the same condition as those of Inishtrahull. They show a more pronounced development of biotite, and from this it may be inferred that they have been more strongly baked. Also, their epidote tends to occur concentrated along crush-zones, rather than to remain in saussuritic pseudomorphs of the type commonly found in Inishtrahull.

V. CAUSE OF THE BAKING OF THE INISHTRAHULL GNEISS.

Those geologists who do not believe that the Lewisian Gneiss occurs anywhere in Ireland probably consider the rocks of the island of Inishtrahull to be foliated portions of the Donegal granite, which occupies such a large area in north-western Donegal. The main mass of the Donegal granite runs south-west from near Mulroy Bay to a little south-west of Glenties, and northward from Glenties to Bloody Foreland. It reappears again in Tory Island and cuts the promontories around Fanad Head and Dunaff Head. It apparently underlies most of the region to the north-west of Dunaff and reaches the surface in one or two outcrops in the Malin Head district. (Fig. 2.) The contact relations of the granite have recently been described by Andrew.[1] According to Andrew, who knows Donegal well, the granite is foliated parallel with the margin, and locally the foliation is intense and parallel with the foliation of the country rocks. The darker portions of the marginal rock are described as xenoliths of biotite-schist of sedimentary origin hitherto considered as sheared granite or foliated modifications of the granite. It is believed that the gneissose structure of the rock designated granite is due to flow of a partly crystallized mass, consisting of biotite and accessories in suspension in a freezing mother-liquor consisting essentially of quartz and felspar. It has been put forward in this paper that the rocks of Inishtrahull are gneisses derived from igneous rocks, and that they have been crushed and subsequently baked. Although there is no field evidence in support, the writer believes that the Inishtrahull gneisses have been baked by the Donegal granite which, as already mentioned, probably occupies a considerable area under this part of Donegal.

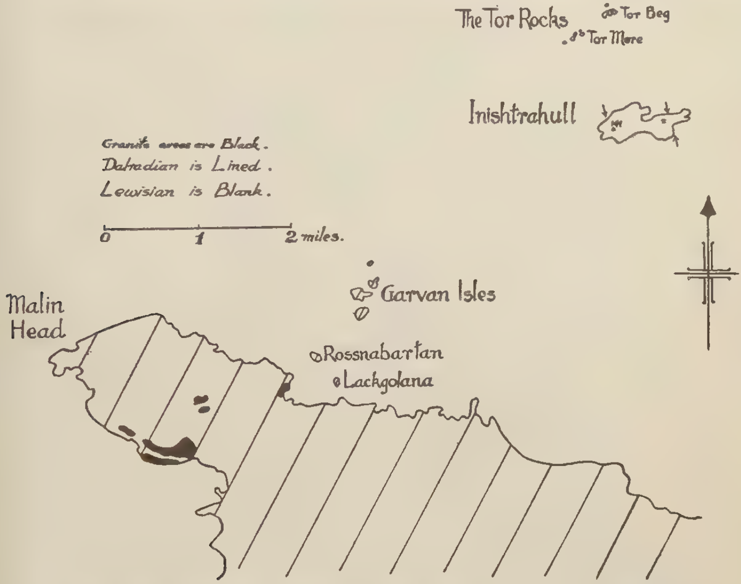

FIG. 2.—Sketch-map of the most northerly part of Ireland.

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[1] *Mem. and Proc. Manchester Lit. and Phil. Soc.*, lxxii, 1927–8, p. 211.

VI. Bearing of the Inishtrahull Gneiss on the Continuation of some Structure-Lines of Scotland.

Professor Bailey[1] has proposed the name of Loch Gruinart Fault for a dislocation which, passing along the hollow of Loch Gruinart in Islay, separates the Lewisian and Torridonian rocks of the Rhinns from the remainder of the island. Further, Bailey considers the Loch Gruinart Fault to be the southerly continuation of the Great Glen Fault (Fig. 3).

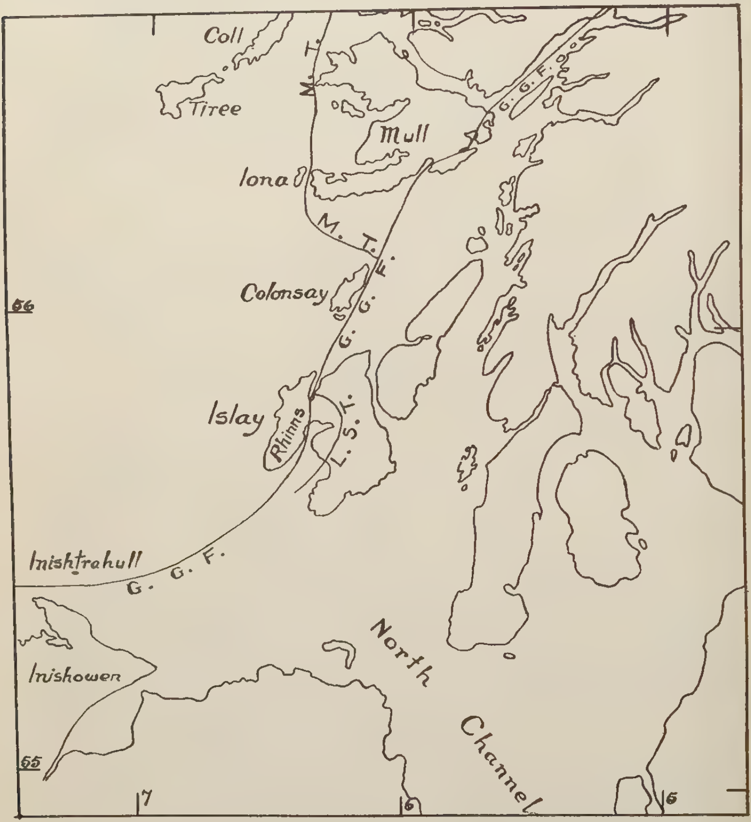

Fig. 3.—Sketch-map of South-Western Scotland and Northern Ireland.
M.T. = Moine Thrust.
L.S.T. = Loch Skerrols Thrust.
G.G.F. = Great Glen Fault.

The Moine Thrust is supposed to lie to the east of the Lewisian and Torridonian rocks of the islands to the west and south-west of Mull, e.g. to the east of Iona and Colonsay. The Lewisian

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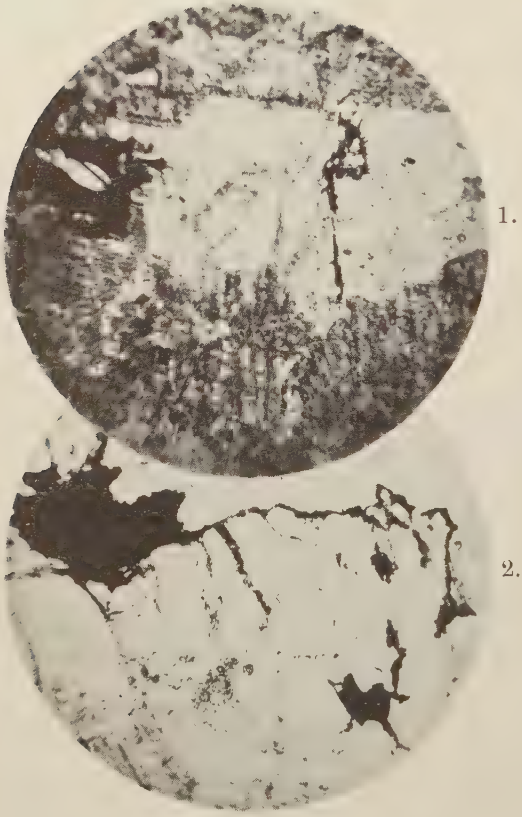
[1] *Q.J.G.S.*, lxxii, 1917, pp. 132–59.



INISHTRAHULL GNEISSES.

and Torridonian rocks of the Rhinns of Islay are below the Loch Skerrols Thrust, which Bailey has correlated with the Moine Thrust.

Continuing the geology on the flanks of these structure-lines to the south-west we find Lewisian Gneiss in Inishtrahull Island and Dalradian rocks in the Garvan Islands and the mainland of Donegal. It seems highly probable that the Great Glen Fault (or Loch Gruinart Fault as it is called in Islay) passes between Inishtrahull and the Garvan Islands as indicated in Fig. 3. The crushed condition of the Inishtrahull Gneiss seems to agree with the belief that there is also the continuation of the Loch Skerrols Thrust overlying the island and separating it from the rocks to the south. On this point, however, there is considerable doubt.

VII. Conclusion.

In conclusion the writer wishes to make acknowledgment for a grant from the Carnegie Trust for the Universities of Scotland to defray travelling expenses in Ireland; to Professor Bailey of the University of Glasgow for constant and generous help during the preparation of this paper and for the trouble he has taken in discussing the problem with his late colleagues in the Geological Survey; to the University of Edinburgh and to the Geological Survey for the loan of slices from Iona and Islay; and also to Dr. Tyrrell for help in the identification of the secondary biotite.

EXPLANATION OF PLATE XXVI.

Fig. 1.—The greater part of this photograph represents a calcic plagioclase converted into granules of epidote (turbid grey) and alkali-felspar (clear) free from epidote in large central area. The black patch to the left is hornblende enclosing apatite (clear). Crossing the plagioclase and enclosed within it is a vein of new biotite. × 22.

Fig. 2.—The black represents greenish-brown biotite running along cracks in the clear felspar. Above the felspar beyond the biotite is a vein of granulitic quartz. × 22.

Erosion of Elevated Fringing Coral Reefs.

By J. Edward Hoffmeister, University of Rochester.

Paper read before the Geological Society of America at its meeting at Washington on 28th December, 1929, and published with permission of the Director of the Bernice P. Bishop Museum, Honolulu.

Two papers bearing the same title have recently appeared in this magazine on the geology of Mangaia and Rurutu, two small islands located in the western part of the South Pacific Ocean.

The first article, written by Mr. L. J. Chubb,[1] compared the geology of the islands and pointed out the chief features in which they were similar or different. Both islands have a central volcanic cone surrounded by a "coral reef" limestone (Makatea) with an average elevation of 200 feet. Beyond this is said to be a living fringing reef at sea-level.

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[1] Chubb, L. J., "Mangaia and Rurutu—a Comparison between two Pacific Islands," Geol. Mag., Vol. LXIV, 1927, p. 518.

The chief feature in which they differ is that the raised "coral limestone" of Mangaia forms a complete ring around the island separated nearly entirely from the volcanic area by a series of swampy flats (Taro Flats) which are only slightly above sea level, while in Rurutu the greater part of the volcanic ground slopes directly to the top of the limestone ring. The only exception to the latter condition is in the south-eastern part of Rurutu where the Paparia Valley runs parallel to the coast and thus separates the volcanic rock from the Makatea.

Dr. Marshall,[1] in his interesting work on Mangaia, has interpreted the swampy flat as a lagoon lying between the volcanic cone and a small elevated barrier reef. Mr. Chubb has explained the existence of the Paparai Valley as due to subaerial erosion. He believes the drainage from the volcanic slopes made "its way to the sea through fissures in the limestone which were gradually enlarged into caves". Then subsequent tributary streams flowed along the volcanic-limestone contact and undermined the limestone, causing it to retreat. This retreat would be accompanied by the formation of a valley lined on the seaward side by a steep limestone cliff and by sloping volcanic hills on the landward. He suggested that "this process may have taken a part, perhaps only a small one, in the shaping of the depression containing the Taro Flats of Mangaia".

Dr. Marshall,[2] in a recent article in the GEOLOGICAL MAGAZINE, defended his interpretation of Mangaia and offered additional evidence based on his study of the neighbouring island of Atiu. He also states that although he cannot discuss the Rurutu structure, as he has never visited the island, it seems reasonable to suppose that the Paparai Valley was also formed in the same manner as the depressions at Mangaia and Atiu, that is, as a lagoon behind a barrier reef.

He apparently bases his belief in this last statement on the assumption that wherever streams flow from volcanic ground on to a Makatea which is directly connected with it, they flow across the Makatea into which they cut deep gorges. He calls attention to this condition all around Rurutu with the exception of the Paparai Valley. He also cites Mango Island of the Fiji group and Christmas Island in the Indian Ocean as similar examples. He says on page 389, "It would thus appear that in those islands where the Makatea may be regarded as an old fringing reef the streams run straight off the volcanic rock into gorges in the Makatea."

Now it is true that none of us have seen the Paparai Valley, not even Mr. Chubb, who obtained his information second hand, so that it is impossible to make any very definite statements regarding its origin. However, from the meagre knowledge on hand concerning it, it would seem to me that Mr. Chubb's explanation of subaerial erosion is the more plausible. At least I am fully convinced that streams which flow from volcanic slopes on to an elevated fringing reef or Makatea do not always flow across it and produce gorges. On the other hand, I have no doubt that many streams after they have reached the surface of the limestone disappear underground and journey to the sea by way of the limestone-volcanic contact. I am also convinced that such a condition will eventually lead to the formation of a valley lined on one side by the sloping volcanic hills and on the other by a nearly vertical limestone cliff.

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[1] Marshall, P., "Geology of Mangaia," *Bernice P. Bishop Museum Bulletin* 36, Honolulu, 1927.

[2] Marshall, P., "Mangaia and Rurutu—a Comparison between two Pacific Islands," GEOL. MAG., Vol. LXVI, 1929, p. 385.

A good example of the above situation exists on the island of Eua, Tonga, where I have recently spent two and one-half months as a Bishop Museum Fellow.

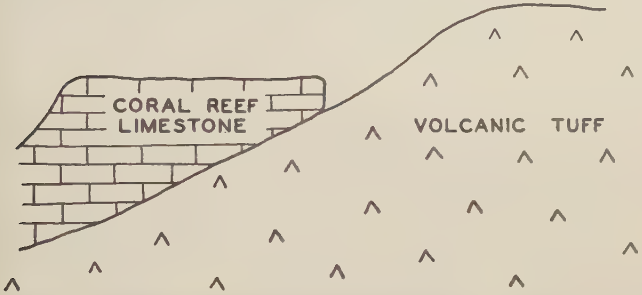

FIG. 1.—Cross section showing depression made by solution of coral limestone on western slope of eastern ridge of Eua, Tonga Islands.

Eua lies at the southern end of the Tonga group in about latitude 21 degrees 20 minutes south, and longitude 175 degrees west. The long axis of the island lies nearly directly north and south. The widest part is near the middle of its length, and it tapers to points at the two ends. It is roughly $12\frac{1}{4}$ miles from the northern to the southern tip. A high ridge extends along the eastern side of Eua for nearly its entire length. The eastern or windward side of the ridge is lined by steep cliffs halted by occasional terraces. The western side slopes more gently toward the central valley of Eua, which is a trough elongated in a north-south direction. Volcanic tuff outcrops in many places along the summit of the eastern ridge. Near the centre of its length, volcanic slopes lead from the summit in a western direction. The entire western slope, with the exception of its northern end, is covered with very dense vegetation, so that physiographic and structural details are not visible from the summit, but can be determined only after a close investigation. In descending the volcanic slopes one is nearly always halted by a vertical limestone cliff which rises 40 to 80 feet. Thus all along in this central area for a distance of at least two miles, there are fragments of this vertical cliff marking the separation between the limestone and the tuff. Water from the slope goes under the limestone, and follows along the contact on its way to the sea.

It is obvious that the top of the limestone was at one time continuous with the volcanic slope, and that the latter has been gradually uncovered by stream erosion. The cliff is formed by the undermining of the limestone and gradual solution of the blocks fallen from above. In this way the cliff is slowly retreating down the side of the slope, which is itself moving westward.

Figure 1 illustrates the condition just described. The limestone itself is hard and compact, but shows some coral structure. It, in all probability, represents a fringing coral reef which formed against the volcanic slopes. Its top is about 450–500 feet above sea level. Its width is variable, but where it can be best observed, measures about 700 feet. The horizontal distance between the top of the cliff and the volcanic slope is also variable, in places less than 200 feet, and in others 300 feet. The actual valley bottom is considerably less than this. A brief examination of this narrow depression shows conclusively that it is too small ever to have been a lagoon and that it is certainly the result of erosion. From the western edge of the old fringing reef a limestone slope leads down to the central valley.

Marshall tried to show that " If the sub-marginal depressions of these islands (Mangaia, Atiu, and Rurutu) had been formed by recession of escarpments the following lines of evidence should be available :—

1. Stream flow along the base of the Makatea cliff as shown by :—
    (*a*) Definite slope
    (*b*) Stream deposits at base of cliff
    (*c*) Undercutting of cliffs
    (*d*) Boulders at base of cliffs.
2. Deep recesses to the entrance of the underground channels.
3. Tracts where the limestone remained in contact with the volcanic rock ".

He contended that since these things were not in evidence, or in some cases only slightly so, the theory of solution could not hold. Let us examine the Eua condition in reference to some of these points.

1*b*. There is very slight evidence of stream deposition at the base of the limestone cliff. Any material in suspension in the small streams seems to be carried beneath the reef.

1*c*. There is some undercutting of the cliff in places, but on the whole it is rather entire.

1*d*. Boulders are found in places at the cliff bases, just as they are occasionally found at Mangaia, etc. They are not numerous, however. More boulders would be expected in Eua as the bottom of the depression is high above sea level and the erosive process is going on at a relatively rapid rate.

2. In Eua, likewise, there are no deep recesses where streams enter the subterranean channels. There are in places caves with wide openings just as are described at Lake Tariara in Mangaia. Here in Eua also the entrance is often through a sinkhole, which cannot be seen until one actually reaches the foot of the cliff.

These show that even in places where solution is undoubtedly the factor which has caused the depression, the conditions are practically no different from what is found at the other islands under discussion.

The primary purpose of this paper is to show that where streams run from volcanic rock on to old fringing reefs, they do not always cut across the reefs and form gorges, but may form depressions similar to that found at Mangaia. Whether those depressions at Mangaia and Atiu were formed in like manner, I hesitate to voice a definite opinion. That there is some evidence to indicate that such was the case, however, is demonstrated by the following points:—

1. If the depressions at Mangaia and Atiu were originally old lagoon bottoms it seems rather odd that there are no passes through the Makatea. It is extremely unusual, to say the least, to find a barrier reef completely encircling an island and preventing any connection, except at high tide, between the lagoon and the ocean.

2. From the map it is clear that the depressions are widest in places opposite the streams. This is what one would expect to find if the valleys were the result of subaerial erosion.

3. At Mangaia, the composition of the red soil of the Makatea suggests that it "is in origin a completely lateritized remnant of basaltic material mixed with some phosphoric acid derived from bird excrement". Dr. Marshall is somewhat at a loss to account for the manner in which it was brought to the Makatea, since the physiography of the island shows no volcanic action subsequent to the beginning of the formation of the reef. He offers the theory that the red soil was carried from the central volcanic hills to the Makatea by birds for the construction of their nests. If the Makatea once represented a fringing reef instead of a barrier reef, as Marshall believes, the presence of the basaltic soil could much more plausibly be explained as having been carried from the volcanic hills by streams flowing directly to and over the reef surface.

4. The discovery of the foraminifer *Lepidocyclina* has led Marshall to assign a Miocene age to the so-called barrier reef. It follows that the reef must either have remained at sea level all during the Pliocene and later times and have been elevated comparatively recently or was elevated at the close of the Miocene and has been above the sea ever since that time. In the event of the first

alternative being correct, one would expect to find, as Davis[1] has pointed out, the lagoon filled with detritus washed down from the volcanic highlands and washed in from the reef. The lagoon, however, is exceptionally free from such detritus. On the other hand, if the reef had been above the sea since the close of the Miocene, it should show evidence of much subaerial erosion. If it is regarded as a barrier reef a remarkably small amount of dissection has taken place during so long a time. Marshall concludes from this that rain water has very little effect on elevated coral reef rock. Davis takes the stand that the discovery of *Lepidocyclina* does not necessarily imply a Miocene age, and assumes that the genus survived longer in this part of the Pacific than elsewhere. Neither of these stands appear to be very tenable. In all elevated reef limestones that I have observed in Tonga and Fiji erosion has played a large part. The finding of *Lepidocyclina* is a significant factor in the interpretation of this reef and cannot be lightly pushed aside. A more plausible explanation, and one that fits in well with the observed facts, is that the limestone mass was at the time of elevation a broad fringing reef which has subsequently been greatly eroded so that a depression resembling a lagoon now exists between its outer rim and the volcanic hills. This would indicate a tremendous amount of erosion instead of a little in the ample time provided since uplift, and would also account for the lack of detritus in the depression.

Studies in Avonian Brachiopoda: III. The Delthyrium of *Chonetes comoides*.

By T. Neville George, M.Sc., Ph.D., F.G.S., University College of Swansea.

It is unusual to discover specimens of Palaeozoic Brachiopoda which clearly display the characters of the delthyrium; in particular, very little is known concerning these features in Carboniferous Protremata. The writer has therefore been fortunate in obtaining well-preserved examples of *Chonetes*, in which the ventral pseudodeltidium and the dorsal cardinal process are exhibited in detail. It has also been found possible to determine the internal features of these structures by means of serial sections.

The specimens were collected along the foreshore about ½ mile south-east of Oxwich Church (Glam. 31 S.E.), on bedding planes in the Carboniferous Limestone. At this locality they occur in some profusion, and are associated with giganteid species of *Productus*, *Lithostrotion* cf. *martini*, *Lithostrotion* aff. *irregulare*, *Dibunophyllum* spp. (including *Dibunophyllum bourtonense*), and *Palaeosmilia murchisoni*; it is therefore probable that the horizon of the strata, which contain beds of typical "pseudo-breccia", is high in D_1, or possibly in D_2.

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[1] Davis, W. M., "The Coral Reef Problem," *American Geographical Society, Special Publication No.* 9, 1928, p. 406.

The specimens are typical samples of *Chonetes comoides* (J. Sowerby), agreeing very closely in external characters with the holotype, though the umbonal region of the ventral valve in the latter is rather more prominent. The striae, of which there are about 35 in a width of 10 mm., remain of approximately constant size throughout growth, and increase in number both by intercalation and by dichotomy. The cardinal areas of both valves are well marked, that of the dorsal valve being about a half as wide as that of the ventral. Weathering not infrequently exposes the tubuli that traverse the ventral cardinal area and which, in other species of the genus at least, continue into the cardinal spines; it is clearly evident that these tubuli terminate dorsally as sockets into which fit corresponding denticles along the margin of the dorsal cardinal area—an accessory means of articulation analogous to that which occurs in other groups of Brachiopoda, as, for example, in certain of the Spiriferidae.

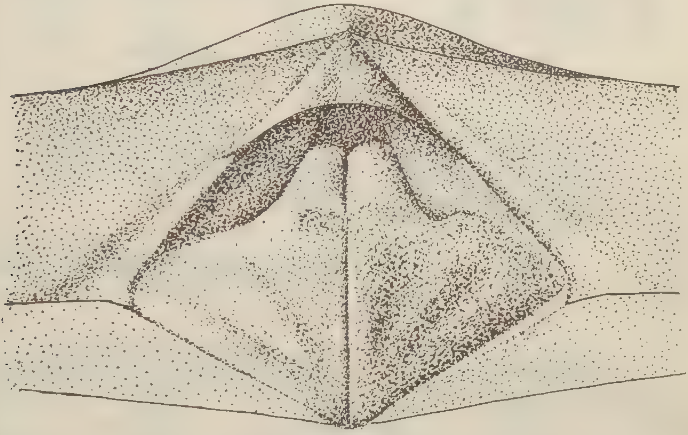

Fig. 1.—The delthyrium of *Chonetes comoides* (J. Sowerby) showing the small triangular pseudodeltidium with its lateral flanges in the ventral valve, and the articulating cardinal area with its median incision in the dorsal valve. × 7.

The delthyrium is wide, and divides the cardinal areas of both valves. The apical portion of the ventral extension of the cavity is partially covered by a small pseudodeltidium that extends superficially about a fifth of the distance towards the dorsal valve. As usual, its anterior border is concave. Growth lines indicate that there is little change in proportions with growth. Although the pseudodeltidium is characteristically triangular in its superficial extent, it is continued beneath the level of the ventral cardinal area as two lateral flanges which extend, gradually becoming narrower, to the teeth. The mid-portions of these flanges are expanded somewhat, and apparently fit into feeble sockets in the cardinal process. Posteriorly, the flanges are attached to the inner side of the pseudodeltidium; their posterior terminations are separated by a small cavity, through which, presumably, the pedicle was protruded.

As in other species of *Chonetes*, the remainder of the delthyrial fissure is occupied completely by the cardinal process.[1] This is a more or less quadrilateral structure, of which the borders facing the ventral valve are concave and apparently articulate with the pseudodeltidium, as has been observed above. The process is divided medianly by a deep narrow incision traversing its entire length; this extends inwards for about a half the thickness of the structure. Externally, each half of the process is faintly trilobed, the more median concavity of each half continuing to the feeble

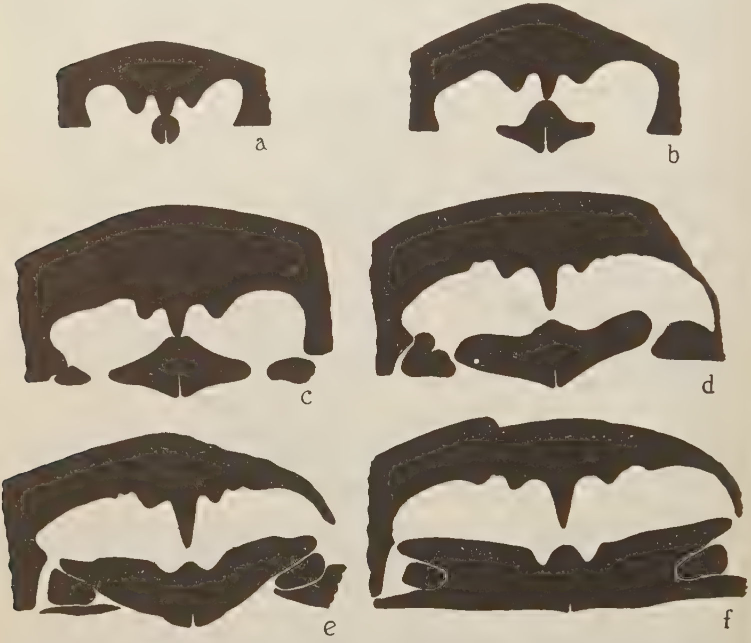

FIG. 2.—Serial sections, approximately 1 mm. apart, through the cardinal area of *Chonetes comoides* (J. Sowerby), to show the internal development, and the median septum and muscular features of the ventral valve. × 3.

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[1] T. Davidson, " British Fossil Brachiopoda," vol. ii, *Mon. Pal. Soc.*, 1858, p. 136.

sockets of supposed articulation. The distal terminations are markedly projecting nodes. There is little change in outline during ontogeny, apart from the median incision, which decreases in depth proximally as the dorsal umbo is approached. Internally, the process is marked by a prominent median elevation, which, as the dorsal umbo is approached, decreases relatively in size, and becomes bounded by two moderately narrow deep depressions that presumably received the divaricator muscles.

The internal features of the ventral valve are typical of the species; the median septum is well developed and is flanked by the clearly delimited narrow adductor impressions and the surrounding broader divaricators.

REVIEWS.

CHAPTERS ON THE GEOLOGY OF SCOTLAND. By the late BENJAMIN NEEVE PEACH, LL.D., F.R.S., and the late JOHN HORNE, LL.D., F.R.S. pp. 1–223, illustrated by numerous photos, maps and sections, 1 coloured map and 1 plate of coloured sections. Oxford University Press: Humphrey Milford. English price 10*s.* 6*d.*

THE time was ripe for a book such as this, for much work has been done in Scotland during the last decade, and in the decade preceding the war, and though most of the results have been published in various Survey Memoirs and in the *Transactions* of different scientific societies, the subject needed treating and presenting as a whole in order that the present state of knowledge should be appreciated. Happy indeed was Scotland in having men of the mental calibre of Peach and Horne to undertake the work, for it was no light task, it needed men of maturity of outlook, and with a most intimate knowledge of both the country and its geology as a whole, to treat the subject adequately; this these authors possessed, and possessed in full measure. Death, alas, has robbed the scientific world of a great geological classic, but the value of even this fragment of the planned book is considerable, and lies in the masterly manner in which there is presented to the reader concise up-to-date statements of the present position of many outstanding problems of Scottish geology.

Seven chapters are here published, and, as we are told in the Appendix, the first five were completed and ready for publication, and hence may be regarded as the final considered work of the two authors. The first chapter is a masterly survey of the physical features of Scotland in relation to the geological structure; Scotland, as we know it to-day, is regarded as being sculptured by various agents of denudation from the south-east side of a high plateau which sloped north-west and south-east but with a steeper slope to the north-west, and hence the drainage to the north-west encroached steadily upon that to the south-east; the book then passes to a review in turn of each of the formations that would be encountered in a traverse from west to east across the classic North-West Area, though the section on the Cambrian is completed by a summary of the present state of knowledge respecting the Highland Border Rocks. Each section is a concise monograph upon the subject with which it deals, studied from the standpoints of stratigraphy, structure, and petrology. This grouping and presentation of the subject matter as a whole is wonderfully illuminating; light is shed upon different problems on almost every page, and suggestions for future work reveal themselves in all directions. Where all is so good it is perhaps invidious to make distinctions, but to the reviewer two chapters are especially striking for their clarity of presentation, when considered in relation to the recognized intricacy of the problems with which they deal; these are the chapter dealing with the Lewisian Gneiss and that on the Highland Metamorphic Rocks. In that on the Lewisian Gneiss we are given, too, the most important results of the authors' own researches on the Outer Hebrides undertaken after they had reached the age limit of service to their country upon the Geological Survey, and carried to a successful conclusion with a zeal and energy that might well be the envy of many a younger man. Throughout these five chapters the terms "mylonite" and "mylonitisation" are used in a very wide sense, greatly extended from that of their original significance. These different mylonites have undoubtedly been formed under very different P.T. conditions, and surely we may hope in the future to discriminate between them, even though they may appear to grade into each other; in the meantime many readers unfamiliar with the publications of the Scottish Geological Survey may be puzzled by the use of the term "flinty crush" both as synonymous with (pp. 40, 44) and distinct from mylonite (p. 52). A footnote would be helpful here. Chapters VI and VII have a different scientific value from the first five, since they represent the views of Peach alone on part of the "Dalradian" Schists. With most of these views Horne is known to have disagreed, and many of a younger generation would probably follow Horne in this respect. For British geologists, however, these two chapters have a special charm, for they vividly recall Peach, the brilliant and stimulating field worker, the inimitable drawer of sections, and the most daring of generalisers.

It is in every way worthy and characteristic of these two great geologists that they have dedicated their book to Lapworth, the third of the mighty trio who have made such brilliant contributions to Scottish geology. This then is their legacy to the science they loved so well: we can give no higher praise than to say it is worthy of the men who gave it. It must be read and studied to be appreciated; so to all interested either in the geology of Scotland or in the wider study of the problems presented by the oldest rocks of our earth we would say "read and enjoy".

It remains but to add that the book is admirably got up both as regards letterpress and illustrations by maps, sections, and photographs; the Oxford University Press is to be congratulated and thanked for their co-operation in helping to bring out the book as a worthy memorial to the authors, at so reasonable a price.

G. L. ELLES.

SUMMARY OF PROGRESS OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN FOR 1929. Published by H.M. Stationery Office. Pt. 1, 2*s.*; Pt. 2, 2*s.*

THE Summary of Progress for 1929 is again divided into its useful two parts. Part 1 contains the reports on the general routine work in the different areas, and a special account of the satisfactory results that continue to be achieved with the Eötvös Balance, particularly in regard to the Portobello fault. Moreover, further work of this nature is promised with a Schmidt Magnetic Balance, which has proved to be quicker, simpler, and less costly to use. This instrument has already been tested with success in tracing the buried course of the Swynnerton dyke.

In the palaeontological section it is disappointing to find the Survey still maintaining their old delimitation of the Caradocian in spite of all that recent work has shown. The faunal break, both as regards the shelly and the graptolitic faunas, is so clearly above the horizon of *N. gracilis* and not below it, that it seems a pity that this fact should be so completely ignored. The discovery of the *N. gracilis* fauna associated with the Hoar Edge Grit seems further to emphasize the equivalence of this grit with that of Spy Wood, a fact which carries with it some important stratigraphic considerations.

Part 2 contains several excellent short Memoirs, of which the most arresting are certainly the one dealing with the Magnetic Survey of part of Leicestershire by Hallimond, and that on the hornfelses from Kenidjack, Cornwall, by Tilley and the Director; this last contains a wealth of new information, and indicates the advantage gained by securing the co-operation of a specialist who can devote much time both to the field work and to working out the results.

G. L. E.

THE SURFACE HISTORY OF THE EARTH. By J. JOLY, Sc.D., F.R.S. 2nd edition., pp. 211, with xiii plates, 11 text-figs., and a coloured map. Oxford: Clarendon Press. 1930. 8*s.* 6*d.*

THE new edition of this work contains nineteen more pages than the first, although the lecture delivered to the Geological Society in May, 1923, is omitted, a matter of regret to readers, as well as to the author. It is evident therefore that a good deal of new matter has been included. It is not proposed, however, to discuss all this in detail. A few words of a general character may, however, be said as to one matter concerning the geological aspect of Professor Joly's scheme of revolutions, which does not seem to have received quite sufficient attention. In the course of many years' work on the geographical and chronological distribution of ore-deposits in many parts of the world, the reviewer has been obliged to study in some detail the geological time-relations of the folding and igneous activity which are in most cases the immediate preludes to primary mineralization. Now in many regions of the world, as in Africa and southern Asia, these periods of diastrophism do not fit in at all well with Professor Joly's clean-cut " revolutions ", but tend rather to interdigitate with them. This subject requires much further investigation, but at present it certainly does not appear that any revolution is of world-wide occurrence and separated off from those preceding and following it by periods of general calm, as seems to be required by the theory set forth in this book. Indeed, it seems to fit the facts better to suppose that diastrophism due to deep-seated disturbances has been in progress in some part of the world nearly all the time. The definite answer to this problem cannot be given yet, but must await much more detailed stratigraphical correlation of the rocks in widely separated regions of the world. The bearing of this aspect of the case on the question of continental drift also needs investigation.

With the subject just named Professor Joly deals very briefly in the Appendix to Chapter X. His treatment, in fact, does not amount to much more than a reference to the well-known *Symposium* published by the American Association of Petroleum Geologists in 1928, and he does not commit himself to any definite statement of opinion on the Taylor-Wegener theory. In this he is probably wise, in view of the present state of our knowledge and the strong opposition to the theory of many mathematicians and of some eminent geologists.

R. H. R.

One of the Royal Medals has been conferred by the Council of the Royal Society on Dr. John Edward Marr, F.R.S., Emeritus Professor of Geology in the University of Cambridge, who retired from the Woodwardian Chair of Geology at the end of the last academical year. Professor Marr has also been elected an Honorary Fellow of the Royal Society of Edinburgh. The editor of this Magazine feels sure that all readers will desire to associate themselves with him in offering hearty congratulations to his former chief and happily still continuing editorial adviser on these so well-deserved honours.

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